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Deformation temperatures, vorticity of flow, and strain in the Moine thrust zone and Moine nappe: Reassessing the tectonic evolution of the Scandian foreland–hinterland transition zone

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ABSTRACT

Examination of deformation temperature, 3-D strain and flow vorticity (W_m) in mylonites from the Assynt-Loch More region of the Moine thrust zone (MTZ) allows quantitative kinematic and thermal characterization of shearing at the base of the Scandian (435–425 Ma) orogenic wedge. Quartz microstructures and c-axis fabric opening angles from mylonites in the immediate hangingwall and footwall to the Moine thrust suggest that deformation temperatures are highest in the eastern part of the Assynt region (including mylonites close to alkaline intrusive complexes) and decrease along strike both to the north (Stack of Glencoul – Loch More) and to the south (Knockan). Quartz c- and a-axis fabrics, together with limited 3-D strain data, indicate that deformation in both the footwall and hangingwall mylonites dominantly involved plane strain to general flattening, although domains of more constrictional flow are identified adjacent to thrust transport-parallel lineaments in the overlying Moine nappe. Rigid grain analyses indicate a remarkably constant flow vorticity for tens of kilometers along orogenic strike (40–60% pure shear) in both the hangingwall and footwall mylonites. Integration with previously reported strain and vorticity estimates from the Assynt region indicates a 50–75% sub-vertical shortening perpendicular to gently dipping foliation, that must have been accommodated by either volume loss or extrusion of material toward the synorogenic topographic surface. Extrusion implies a causal link between upper and lower crustal processes, with significant implications for the kinematic and geometric evolution of the Scandian wedge.

1. Introduction

Recent integration of vorticity and strain studies indicates that ductile deformation in the hinterland regions of collisional orogenic systems (High Himalaya, Scottish Caledonides, European Alps, Greek Hellenides, Appalachian Blue Ridge) involves a significant component of pure shear deformation (Kassem and Ring, 2004; Law et al., 2004; Jessup et al., 2006; Bailey et al., 2007; Larson and Godin, 2009; Law, 2010; Thigpen et al., 2010; Xypolias et al., 2010). Kinematic and mechanical models that attempt to explain thrust kinematics and wedge dynamics (Chapple, 1978; Davis et al., 1983; Dahlen et al., 1984; Platt, 1986; Dahlen, 1990; Holdsworth and Grant, 1990; Willett et al., 1993) must take these pure shear components into account. Major theoretical implications of a significant pure shear contribution to ductile deformation include: 1) vertical ductile thinning contributes to synkinematic exhumation of progressively lower portions of the orogenic wedge (Feehan and Brandon, 1999); 2) under approximately plane strain isochoric conditions, vertical ductile thinning leads to significant transport-parallel lengthening of thrust sheets, driving ductile extrusion toward the synorogenic topographic surface. In the former case, vertical ductile thinning acting in conjunction with erosion and normal faulting generates rapid synkinematic exhumation which may, in turn, explain preservation of inverted metamorphic isograds observed in the structurally lower levels of many orogenic wedges (e.g. Stephenson et al., 2000; Vannay and Grasemann, 2001; Kidder and Ducea, 2006) by vertical ductile thinning of the overlying nappe pile (Ring and Kassem, 2007). Ductile extrusion toward the synorogenic topographic surface has kinematic, geometric, and strain rate implications for deformation occurring at upper crustal levels (Williams and Jiang, 2006) and may result in kinematic and dynamic linkage between lower crustal ductile processes and upper crustal brittle processes (Northrup, 1996).

The majority of previously published vorticity studies have focused on identifying variation in vorticity and 3-D strain with change in structural depth along orogen normal sampling

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transects. Many of these studies have almost exclusively related vorticity variation to either structural position or to rheologic partitioning controlled by lithologic variation (e.g. Sullivan, 2008). However no studies have, to date, examined whether significant variation of flow vorticity occurs along orogenic strike. In this paper we first present new vorticity and deformation temperature data obtained from Moine thrust zone (MTZ) samples collected along strike at the base of the Scandian orogenic wedge exposed in northwest Scotland (Fig. 1). The sampling traverse is approximately 30 km in length and extends from Loch Dionard southwards through the eastern part of the Assynt district to Knockan (Fig. 2). A complementary quartz petrofabric study allows the plane strain vs. non-plane strain and coaxial vs. non-coaxial components of the deformation to be qualitatively characterized. We then discuss the tectonic significance of a pure shear contribution to ductile flow, as well as the factors that may influence variation in flow both along and across orogenic strike. Variation in estimated flow vorticities is examined with respect to lithology, deformation temperature, 3-D strain type and structural position within the nappe stack, as well as with respect to footwall structural architecture.

2. Tectonic setting

The Scandian orogenic wedge exposed in northwest Scotland (Fig. 1) is the composite result of at least three structural-thermal events, including the Knoydartian thermal event (820–730 Ma) and the Grampian (475–460 Ma) and Scandian (435–415 Ma) phases of

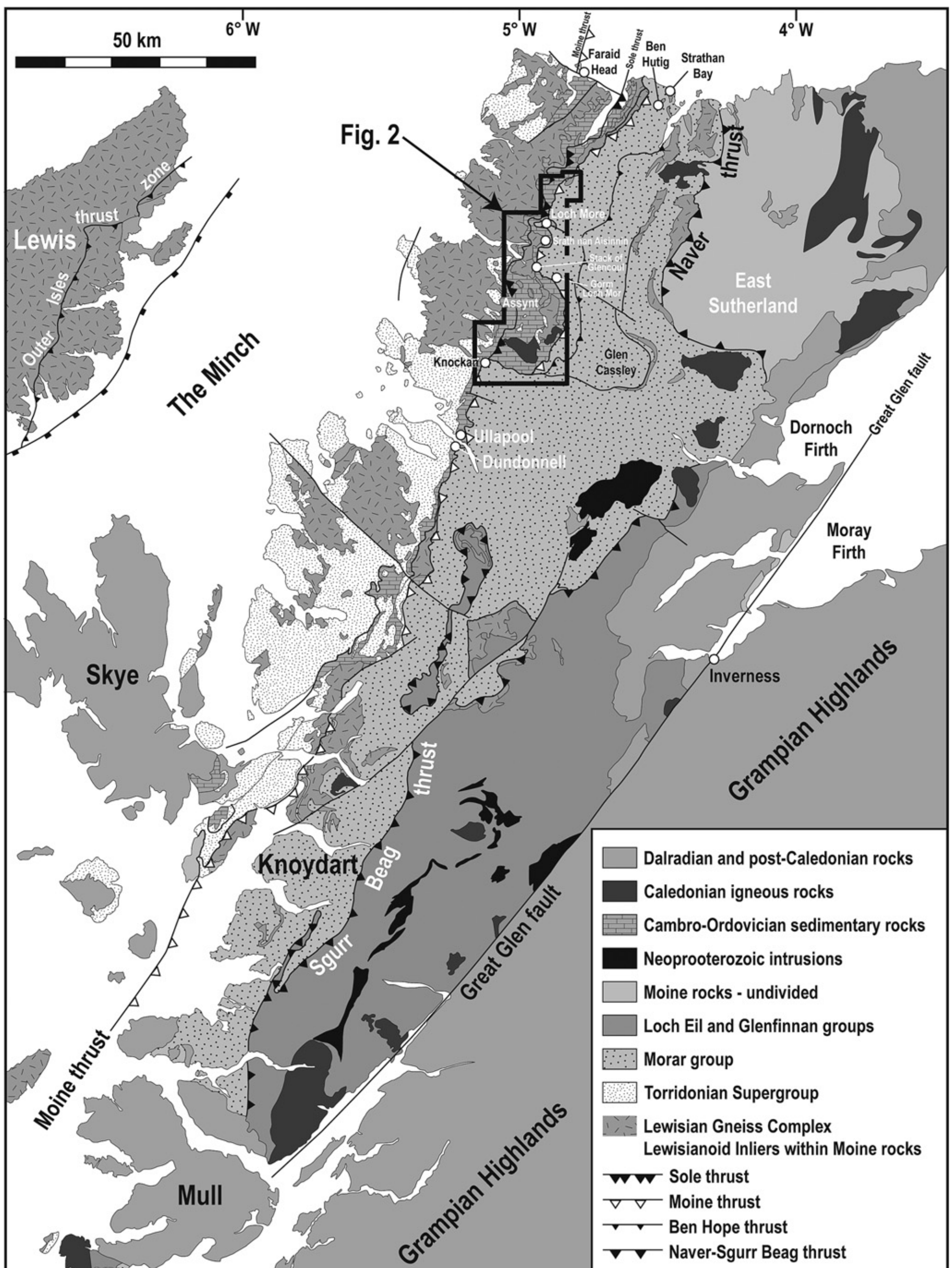

Fig. 1. Geologic map of northern Scotland. Location of Fig. 2a is shown. Modified from Krabbendam et al. (2008).